



High-speed OTDM switching

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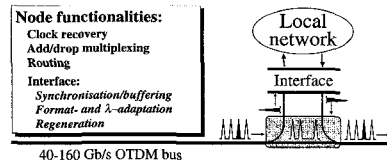
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CMA8:00 am–10:00 am
Room 100**Optical TDM Systems**Fred Heismann, Bell Labs/Lucent
Technologies, President**CMA1** Fig. 1. Top: OTDM bus used for long-distance interconnection of large regional networks with add/drop functionality.**CMA1 (Invited)**

8:00 am

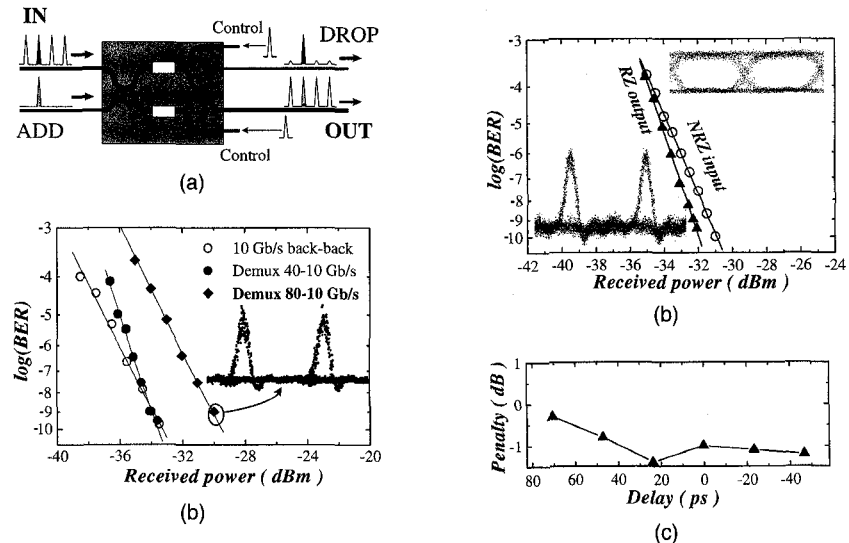
High-speed OTDM switching

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The speed limit for electronic switching and signal processing is currently 30–40 Gbits/s, and thus optical techniques are needed in order to fully exploit the transmission bandwidth of optical fibers. Two complementary techniques for optical multiplexing exist, namely, optical time division multiplexing (OTDM) and wavelength division multiplexing (WDM). In both technologies the basic multiplexing and demultiplexing is carried out in the optical domain, but more advanced signal processing such as switching and regeneration can also be performed all-optically, i.e., without any optoelectronic conversion. WDM offers simple (passive) demultiplexing and routing of the optical channels, while, on the other hand, OTDM has transmission advantages such as simultaneous dispersion compensation and regeneration of all channels, reduced requirements to erbium-doped fiber amplifier gain flatness, and zero cross talk from four-wave mixing (FWM) or stimulated Raman scattering (SRS). As such, OTDM is well suited for “backbone” networks with long spans and few nodes but is also being considered for ultrahigh-speed local area networks (LANs). Several research groups and projects are currently investigating OTDM technology,^{1–5} and the state of the art currently allows point-to-point transmission followed by clock recovery and demultiplexing of up to 400-Gbit/s signals.⁴

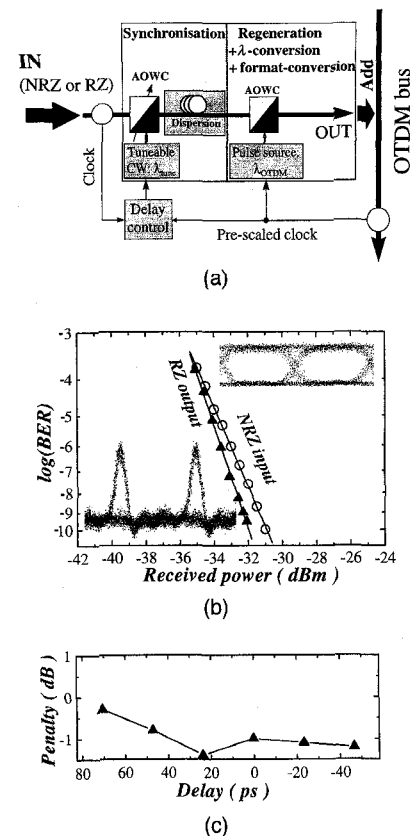
Besides the techniques needed for point-to-point transmission, networking issues are also important in OTDM systems. As an example, consider WDM islands or OTDM rings, which are interconnected by an OTDM bus as shown in Fig. 1, which also lists the key functionalities needed in an OTDM network. At the network nodes, add/drop multiplexers (ADM) are placed for dropping (demultiplexing) channels from the bus and inserting new channels into the vacant timeslots. If the “add” channels originate from remote locations, an all-optical bit alignment and regeneration prior to adding is essential. In packet-switched networks, methods for dynamic header processing and routing and packet buffering are also needed.

High-speed all-optical signal processing/switching such as clock recovery, demultiplexing, header processing, and buffering has been demonstrated at very high speeds using electroabsorption modulators, FWM in semicon-

**CMA1** Fig. 2. (a) One possible realization of add/drop multiplexer: SOA-based Mach-Zehnder interferometer (produced by ETH-Zürich), controlled by injection of short optical control pulses. (b) Examples of demultiplexing from 40 and 80 Gbits/s to 10 Gbits/s using SOA-MZI. Inset shows output eye in the case of 80 Gbits/s demultiplexing. (c) Add multiplexing at 40 Gbits/s using SOA-MZI. Insets show cleared time slot and signal with a 10-Gbit/s channel added in the cleared time slot. Bit-error-rate (BER) curves are measured after demultiplexing using electroabsorption modulator.

ductor optical amplifiers, and a variety of NOLM schemes using both fiber- and semiconductor-based nonlinearities. Also, SOAs monolithically integrated in Mach-Zehnder [Fig. 2(a)] or Michelson interferometers (SOA-MZI or SOA-MI) have proven to be a flexible solution as, e.g., add/drop multiplexers⁶ and regenerative wavelength and format converters with ultrahigh-speed capabilities. Using these structures, stable, bit-rate flexible demultiplexing can be performed as shown in Fig. 2(b). Moreover, the devices enable an efficient clearing of time slots for performing add multiplexing, as seen in Fig. 2(c).

A further example of the application of this type of device in the context of OTDM networking is given in Fig. 3. Here two all-optical SOA-MI wavelength converters (AOWCs) are cascaded to perform the tasks of bit alignment,

**CMA1** Fig. 3. (a) Principle for performing synchronization, regeneration, and format and wavelength conversion. Incoming signal can be nonreturn to zero (NRZ) or return to zero (RZ), output signal is RZ. (b) Results for NRZ input signal (RZ output). A sensitivity improvement relative to input of 1 dB is seen. (c) Penalty vs. delay, controlled by adjusting wavelength at first AOWC. BER measurements in (b) are taken for 0-ps delay.

regeneration, wavelength conversion, and, if needed, format conversion, providing the interface from a local network to an OTDM bus.⁷

To summarize, OTDM continues to be of interest both for point-to-point transmission and as a networking technology for both LANs and long-distance transmission. Recent research has demonstrated enabling techniques for OTDM networks at high speeds, and in conclusion, OTDM is emerging as an attractive complement to WDM.

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